

APPENDIX A

10550.422460

Provisional Patent Application of
Balazs Kralik, Michael Goldbach, and Paul Dagum
for

Method and Business Process for Estimation of Component Gating
and Shortage Risks in Assemble-to-Order Manufacturing Operations

CROSS-REFERENCE TO RELATED APPLICATIONS

This invention is related to Provisional Application No. 60/213,189, filed 6/21/2000, which is herein incorporated by reference. It is also related to U.S. Patent Application Nos. 09/412,560, filed 10/5/1999, and 09/491,461, filed 1/26/2000, both of which are herein incorporated by reference.

FIELD OF THE INVENTION

This invention relates generally to manufacturing resource allocation. More particularly, it relates to risk management in the procurement of unfinished goods by estimation of component shortage risk.

SUMMARY

An assemble-to-order (ATO) manufacturing process is one in which products are manufactured from raw components only as orders are received. While ATO processes are more efficient than manufacture-to-stock (MTS) operations, in which products are produced before demand is known, they are not without significant risks. If component availability is below what is required to meet product demand, then fulfillment of orders is either delayed or fails. Conversely, if excess component inventory remains after demand is met, the excess is either returned to the supplier, usually at a loss, or held until future need. Thus any component inventory that does not exactly

meet demand incurs some financial loss for the manufacturer. Being able to predict the risk of component shortage for each component allows a manufacturer to make more informed business decisions.

The present invention addresses this need by providing a novel method for estimating component shortage risk and component gating risk. A gating component is one that is the most short and therefore determines the allowable level of production. Gating risk for a particular component is the risk that the component will be the gating component. Estimation of component shortage and gating risks is particularly complicated when a large number of products are made from a large number of the same components, and thus the present invention is particularly advantageous under such conditions.

Full description of the method of the present invention is contained within the following attached appendices as well as in the patent applications incorporated by reference above:

Appendix A: Invention Disclosure ID-07-00, "Method and business process for the estimation of component gating and shortage risk in assemble-to-order manufacturing operations," Balazs Kralik et al.

Appendix B: Technical Report TR-26-00, "Gating and Shortage Risk," Balazs Kralik and Michael Goldbach.

In addition to a business process and computer-implemented method, the present invention provides a system for computing component gating and shortage risks. The system is preferably a computer system containing a memory, input/output devices, and processing means for implementing the method.

RAP-106/PROV

The present invention also provides a computer-readable medium of instructions executable by the computer to perform method steps for the method described above. The present invention applies equally regardless of the particular type of signal bearing media used. Examples of computer-readable media include: recordable-type media such as floppy disks and CD-ROMs and transmission-type media such as digital and analog communication links.

It will be clear to one skilled in the art that the above embodiment may be altered in many ways without departing from the scope of the invention.

Appendix A:
Invention Disclosure
ID-07-00

STRICTLY CONFIDENTIAL

Title: Method and business process for the estimation of component gating and shortage risk in assemble-to-order manufacturing operations

Inventor(s): Balazs Kralik, Michael Goldbach, Paul Dagum

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0342249-00001

Background of the invention

Problem definition

When possible, it is beneficial for manufacturing companies to produce their outputs in an assemble-to-order (ATO) fashion. While manufacture-to-stock (MTS) manufacturers produce outputs before demand for them is revealed, ATO operations only produce outputs as the order stream arrives.

In an ATO operation, the availability of components is the key variable that controls the ability to produce. If component availability is limited (either because inventory is limited or because supplier commitments to ship the component on demand are insufficient), then fulfillment of demand either fails or is delayed.

If component planners must negotiate component supply contracts (specifying the number of each component to ship in the planning period) before demand is realized, there is a residual risk that some components will be in short supply. Estimating this risk is paramount for informed supply contract negotiation.

Component Shortage Risk quantifies the risk that in the planning period there will be more need than availability for a given component. In other words Component Shortage Risk for component i is the risk that there will be a shortage in component i .

Component Gating Risk quantifies the risk that a particular component will be the cause of order fulfillment failure. Note that in many demand instances more than one component may be short, but one of the components, the one that is most short, is the *gating component*, i.e. the component determining the level of production. Component Gating Risk for component i is the risk that component i will be the gating component.

Problems Solved by the Invention:

Problem 1: How to compute the value of component gating risk

Problem 2: How to compute the value of component shortage risk

This invention makes use of the method disclosed in [1], which in turn makes use of the method disclosed in [2].

Indication of Novelty

The rigorous definition and method of computing gating risk is novel.

Both gating risk and shortage risk computations represents novel uses of the invention disclosed in [1].

Summary of the Invention

The risk measures are computed following these steps

Step 1. Gather the relevant component and product data

- Step 2. Indicate the components for which to compute gating and/or shortage risk
 Step 3. For all components indicated in step 2, compute gating and/or shortage risk.
 Step 4. Return the results

Step 3. contains the novelty and is expanded below.

Detailed Description of a Preferred Embodiment

Gating risk

The first part of the present invention, illustrated in Figure 1, describes a means to compute the gating risk for a set of components.

In step 101, we gather the component and product data. The required data are exactly the ones described in [1].

In step 102, the user specifies which component for which the gating risk should be computed.

In step 103-110 we loop over the components for which gating risk computation is desired.

In steps 105 through 109, we compute the numerical derivative of production with respect to the plan for each component i . In the preferred embodiment, a first order difference is used, however other numerical derivatives could be applied.

In step 105 we first reset the component plan to its original value at the maximum expeditable plan, and then increase the component plan of component i under consideration by a small amount epsilon. Epsilon is set typically to 1% of the component plan of component i .

In step 106 we use the method disclosed in [1] to compute q_{i+} , the mean production under increased component plan i .

In step 107 we first reset the component plan to its original value at the maximum expeditable plan, and then decrease the component plan of component i under consideration by a small amount epsilon.

In step 108 we use the method disclosed in [1] to compute q_{i-} , the mean production under decreased component plan i .

In step 109 we apply formula 3.6 of [3] to compute the gating risk. Explicitly, we evaluate $a_i * (q_{i+} - q_{i-}) / (2 * \epsilon)$ where a_i is the vector of connect rates for component i and q_{i+} , q_{i-} and epsilon have been defined above.

In step 111 the results of the gating risk computation are returned to the user.

Shortage Risk

The second part of the invention is the computation of shortage risk. This consists of the steps described in Figure 2:

In step 201 the component and product parameters are collected. The required parameters are exactly the same as those required for the method described in [1].

In step 202 the user specifies which components the shortage risk is to be calculated for.

In step 203-205 we loop over all the selected components

In step 204 we perform the calculation according to formula 2.1 of the attached technical report, TR-26-00.

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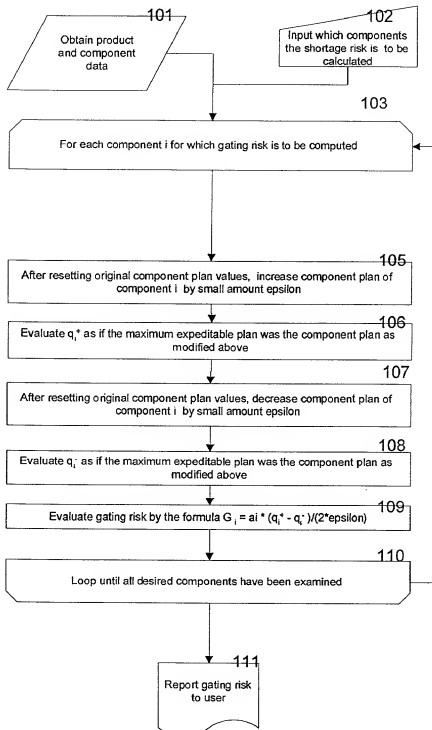


Figure 1 Computing gating risk

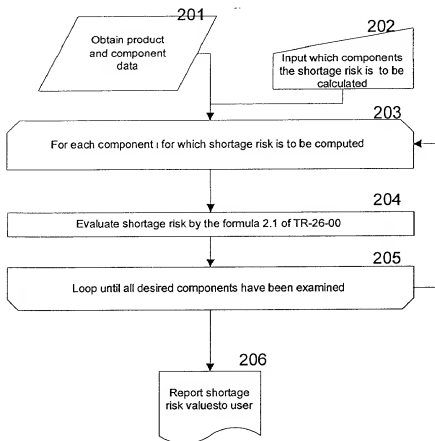


Figure 2 Computing shortage risk

Technical field of the invention

This invention relates generally to manufacturing resource planning. More specifically it relates to risk management in the procurement of unfinished goods.

Statutory Classification of the invention:

- This invention represents a system and method

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References

1. Dagum, P., M. Goldbach, and B. Kralik, *Method and apparatus for the estimation of mean production for assemble-to-order manufacturing operations*. U.S. Provisional Patent Application No. **60/213,189**, filed 6/21/2000.
2. Chavez, T.A. and P. Dagum, *Method and Apparatus for Multivariate Allocation of Resources*. Rapt Inc., 1999. US Patent Application No. **09/412560**, filed 10/5/1999.
3. Kralik, B. and M. Goldbach, *Gating and Shortage Risk*. 2000: Rapt Inc. **TR-26-00**

[illegible]

Balazs Kralik and Michael Goldbach

Technical Report TR-26-00

07-jul-00

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1 Introduction

When possible, it is beneficial for manufacturing companies to produce their outputs in an assemble-to-order (ATO) fashion. While manufacture-to-stock (MTS) manufacturers produce outputs before demand for them is revealed, ATO operations only produce outputs as the order stream arrives.

In an ATO operation, the availability of components is the key variable that controls the ability to produce. If component availability is limited (either because inventory is limited or because supplier commitments to ship the component on demand are insufficient), then fulfillment of demand either fails or is delayed.

If component planners must negotiate component supply contracts (specifying the number of each component to ship in the planning period) before demand is realized, there is a residual risk that some components will be in shortage (unless the supply contract calls for the delivery of infinitely many components). Estimating this risk is paramount for informed supply contract negotiation.

Component Shortage Risk quantifies the risk that in the planning period there will be more need than availability for this component. In other words Component Shortage Risk for component i is the risk that there will be a shortage in component i .

Component Gating Risk quantifies the risk that a particular component will be the most important cause for order fulfillment failure. Note that in many demand instances more than one component may be short, but one of the components, the one that is shortest, is the gating component, i.e. the component determining the level of production. Component Gating Risk for component i is the risk that component i will be the gating component.

2 Shortage Risk

Production is feasible if demand \mathbf{x} falls in the region $\Omega = \{\mathbf{x} : \mathbf{a}_i \cdot \mathbf{x} \leq d_i \quad \forall i\}$, where \mathbf{a}_i are the connect rates and d_i is the maximum component availability for component i . In practical terms, d_i are the *maximum expeditable* levels.

A shortage event occurs if the realized demand \mathbf{x} is such that $\mathbf{a}_i \cdot \mathbf{x} > d_i$. To illustrate the concept, consider the simple case of the p2c2 model illustrated in Figure 1. In this model the regions of demand which correspond to shortage are illustrated in Figure 2.

The shortage risk is always given by the weight of the normal distribution over a halfspace.

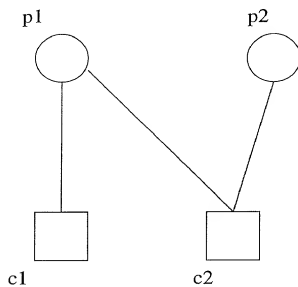


Figure 1: The 2-product 2-component (p2c2) model

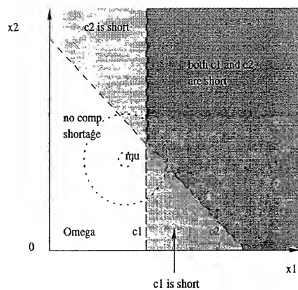


Figure 2: Regions of shortage for component 1, component 2 and both for the p2c2 model

The shortage risk r_i for component i is given by

$$r_i = \int_{d_i}^{\infty} N\left(x; \mathbf{a}_i, \mu, \sqrt{\mathbf{a}_i^T \Sigma \mathbf{a}_i}\right) dx \quad (2.1)$$

where d_i is the maximum expeditable level of component i , $N(x, \mu, \sigma)$ is the normal density with mean μ and variance σ^2 , \mathbf{a}_i is the vector of connect rates for component i , μ is the mean (forecasted) demand, and Σ represents demand covariance.

3 Gating Risk

The regions of gating risk are illustrated in Figure 3. Intuitively, we call component i the gating component given demand \mathbf{x} and component availability \mathbf{d} if the production $q(\mathbf{x}, \mathbf{d})$ falls on the d_i -face of the feasible region Ω .

Definition 3.1 Given a demand event \mathbf{x} , a component plan \mathbf{d} , and a production policy $q: \mathbf{x} \in \mathbb{R}^n, \mathbf{d} \in \mathbb{R}^m \rightarrow \mathbb{R}^n$, we call component i gating if and only if $q(\mathbf{x}, \mathbf{d})$ falls on the face of the feasible region Ω associated with component i . In other words if and only if

$$\mathbf{a}_i \cdot q(\mathbf{x}, \mathbf{d}) = d_i. \quad (3.1)$$

Note: For the local-u production policy (depicted in Figure 3) it is easy to see that the space where more than one component is gating is of measure zero, except in the degenerate case where there are two components i_1 and i_2 such that $\mathbf{a}_{i_1} = \mathbf{a}_{i_2}$ and $d_{i_1} = d_{i_2}$. Exclude this degenerate case from the following discussion.

We can paraphrase the definition of gating risk as: given a demand \mathbf{x} , whichever component actually runs out completely upon producing the production amount $q(\mathbf{x}, \mathbf{d})$ is the gating component.

In order to proceed, consider the function

$$\begin{aligned} g_i(\mathbf{x}, \mathbf{d}) &= \mathbf{a}_i \cdot q(\mathbf{x}, \mathbf{d}) \\ &= \begin{cases} \mathbf{a}_i \cdot \mathbf{x} & \text{if } \mathbf{x} \in \Omega \\ d_i & \text{if } \mathbf{x} \in \bar{\Omega} \text{ and } i \text{ is gating} \\ \hat{g}_i(\mathbf{x}, \mathbf{d}) \leq d_i & \text{otherwise.} \end{cases} \end{aligned} \quad (3.2)$$

$$(3.3)$$

In the above definition, \hat{g}_i is some function which depends on the problem details. Its region of definition $\bar{\Omega}$ is the intersection of $\bar{\Omega}$ with the complement of the region where i is gating.

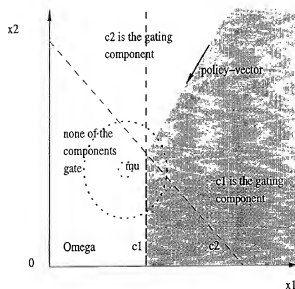


Figure 3: Regions where either component 1 or component 2 is gating for the p2c2 model

For the usual local- u production policy [1], \bar{g}_i has an additional property: in its region of definition, it is independent of d_i . This is the *gate mapping* property:

Definition 3.2 *Gate mapping property:* an allocation policy is gate mapping if the following condition holds for every x : If for both $d = (d_1, \dots, d_i, \dots, d_n)$ and $d' = (d_1, \dots, d'_i, \dots, d_n)$ the gating component is the same $j \neq i$, then $q(x, d) = q(x, d')$.

Corollary 3.3 A production policy is gate mapping if and only if

$$\frac{\partial g_i(x, d)}{\partial d_i} = 0 \quad \text{if } x \in \Psi_i \quad (3.4)$$

3.1 Evaluating Gating Risk

For gate mapping production policies, by definition g_i is independent of d_i , unless component i is actually gating. Conversely, if i is gating then $\partial g_i(x, d)/\partial d_i = 1$ by Equation 3.2. Hence the gating component can easily be identified by examining the derivatives of the g_i .

The gating risk G_i for component i is defined as the probability under the distribution of x that component i is gating. This can be expressed as the expectation:

$$G_i = \int \frac{\partial g_i(\mathbf{x}, \mathbf{d})}{\partial d_i} f(\mathbf{x}; \mu, \Sigma) d\mathbf{x} = \mathbf{a}_i \cdot \int \frac{\partial \mathbf{q}(\mathbf{x}, \mathbf{d})}{\partial d_i} f(\mathbf{x}; \mu, \Sigma) d\mathbf{x} \quad (3.5)$$

While $\frac{\partial \mathbf{q}(\mathbf{x}, \mathbf{d})}{\partial d_i}$ is not differentiable, the integral is uniformly convergent in the Lebesgue sense, and hence the order of integration and differentiation can be reversed:

$$G_i = \mathbf{a}_i \cdot \frac{\partial}{\partial d_i} \int \mathbf{q}(\mathbf{x}, \mathbf{d}) f(\mathbf{x}; \mu, \Sigma) d\mathbf{x} = \mathbf{a}_i \cdot \frac{\partial \bar{\mathbf{q}}(\mathbf{d})}{\partial d_i} \quad (3.6)$$

where $\bar{\mathbf{q}}(\mathbf{d})$ is the mean production given component availability \mathbf{d} .

References

- [1] Paul Dagum, Michael Goldbach, and Balazs Kralik. Demand statistical arbitrage with variants of the uniform production policy. Technical Report TR-14-00, Rapt Technologies Corporation, 324 Ritch Street, San Francisco, CA 94107, January 2000.

Invention Disclosure

ID-07-00

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Title: **Method and business process for the estimation of component gating and shortage risk in assemble-to-order manufacturing operations**

Inventor(s): **Balazs Kralik, Michael Goldbach, Paul Dagum**

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Background of the invention***Problem definition***

When possible, it is beneficial for manufacturing companies to produce their outputs in an assemble-to-order (ATO) fashion. While manufacture-to-stock (MTS) manufacturers produce outputs before demand for them is revealed, ATO operations only produce outputs as the order stream arrives.

In an ATO operation, the availability of components is the key variable that controls the ability to produce. If component availability is limited (either because inventory is limited or because supplier commitments to ship the component on demand are insufficient), then fulfillment of demand either fails or is delayed.

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Problems Solved by the Invention:

Problem 1: How to compute the value of component gating risk

Problem 2: How to compute the value of component shortage risk

Description of the Prior Art

This invention makes use of the method disclosed in [1], which in turn makes use of the method disclosed in [2].

Indication of Novelty

The rigorous definition and method of computing gating risk is novel.

Both gating risk and shortage risk computations represents novel uses of the invention disclosed in [1].

Indication of Unobviousness

Summary of the Invention

The risk measures are computed following these steps

Step 1. Gather the relevant component and product data

Step 2. Indicate the components for which to compute gating and/or shortage risk

Step 3. For all components indicated in step 2, compute gating and/or shortage risk.

Step 4. Return the results

Step 3. contains the novelty and is expanded below.

Detailed Description of a Preferred Embodiment

Gating risk

The first part of the present invention, illustrated in Figure 1, describes a means to compute the gating risk for a set of components.

In step 101, we gather the component and product data. The required data are exactly the ones described in [1].

In step 102, the user specifies which component for which the gating risk should be computed.

In step 103-110 we loop over the components for which gating risk computation is desired.

In steps 105 through 109, we compute the numerical derivative of production with respect to the plan for each component i . In the preferred embodiment, a first order difference is used, however other numerical derivatives could be applied.

In step 105 we first reset the component plan to its original value at the maximum expeditable plan, and then increase the component plan of component i under consideration by a small amount epsilon. Epsilon is set typically to 1% of the component plan of component i .

In step 106 we use the method disclosed in [1] to compute q_{i+} , the mean production under increased component plan i .

In step 107 we first reset the component plan to its original value at the maximum expeditable plan, and then decrease the component plan of component i under consideration by a small amount epsilon.

In step 108 we use the method disclosed in [1] to compute q_{i-} , the mean production under decreased component plan i .

In step 109 we apply formula 3.6 of [3] to compute the gating risk. Explicitly, we evaluate $a_i * (q_{i+} - q_{i-}) / (2 * \epsilon)$ where a_i is the vector of connect rates for component i and q_{i+} , q_{i-} and epsilon have been defined above.



In step 111 the results of the gating risk computation are returned to the user.

Shortage Risk

The second part of the invention is the computation of shortage risk. This consists of the steps described in Figure 2:

In step 201 the component and product parameters are collected. The required parameters are exactly the same as those required for the method described in [1].

In step 202 the user specifies which components the shortage risk is to be calculated for.

In step 203-205 we loop over all the selected components

In step 204 we perform the calculation according to formula 2.1 of the attached technical report.

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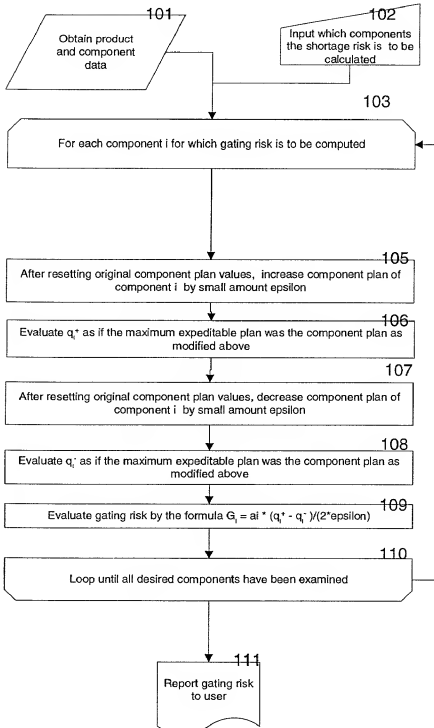


Figure 1 Computing gating risk

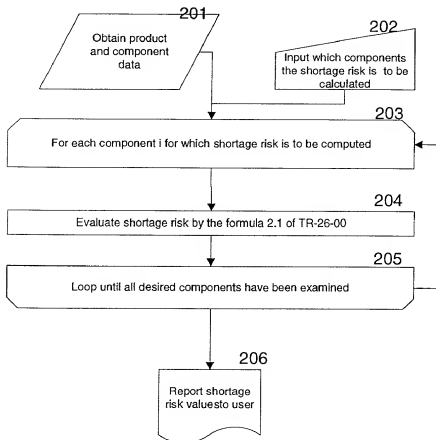


Figure 2 Computing shortage risk

Technical field of the invention

This invention relates generally to manufacturing resource planning. More specifically it relates to risk management in the procurement of unfinished goods.

Statutory Classification of the invention:

- This invention represents a system and method

Conception and Reduction to Practice

- Date of conception: January 2000
- Date of first prototype: February 2000

Public Disclosures and Statutory Bars

- Computation of gating risk was included in Rapt Buy released in March 2000.

Prior Art

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By: _____

By: _____

Name: _____

Name: _____

Date: _____

Date: _____

Witness

I declare that I have read and understood the entire contents of the above invention disclosure on or before the date of my signature below.

By: _____

Name: _____

Date: _____

References

1. Dagum, P., M. Goldbach, and B. Kralik, *Method and business process for the estimation of mean production for assemble-to-order manufacturing operations*. Rapt Inc., 2000. RAPT ID-04-00.
2. Chavez, T.A. and P. Dagum, *Method and Apparatus for Multivariate Allocation of Resources*. Rapt Inc., 1999. US **09/412560**.
3. Kralik, B. and M. Goldbach, *Gating and Shortage Risk*. 2000: Rapt Inc. **TR-26-00**

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